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POSSIBLE EFFECTS OF LATENT HEAT RELEASE IN THE TROPOSPHERE ON THE VERTICAL TEMPERATURE STRUCTURE IN THE MESOSPHERE

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STRUCTURE IN THE MESOSPHERE

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INTRODUCTION

Nearly a score of in situ meteorological soundings of the structure of the mesosphere, conducted over intervals ranging from fractions of an hour to the order of day, have revealed the existence of irregular features which persist from one sounding to the next. These identifiable features (e. g., warm and cold layers) are usually displaced a few kilometers vertically with time, implying propagation of the structure, a characteristic which, at least qualitatively, has suggested periodic, internal gravity waves as the generating mechanism. While this interpretation is readily applicable to the structure observed at high latitudes in winter, a non-periodic generating mechanism may be involved. It is the purpose of this note to describe such a mechanism.

To date, variations in the vertical structure of the atmosphere have been treated by either tidal theory or gravity wave theory. Both of these approaches involve periodic solutions to the atmospheric equations of motion. In tidal theory, the driving force is the periodic solar heating resulting in diurnal, semi-diurnal and other harmonic tides. In gravity wave theory, a periodic solution with frequency $\omega < \omega_B$ is assumed, where ω_B is the Brunt-Vaisala frequency. Periodic gravity wave theory is very useful to calculate wave propagation in the atmosphere, but leaves one rather helpless when it comes to estimating the quantitative characteristics of waves generated by non-periodic atmospheric heat releases, and the behavior of such waves close to the source.

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Recently, Eberstein and Shere (1971) have developed a linearized solution to chemically generated waves in a dilute, isothermal atmosphere. In a restricted reaction zone, heat is released or absorbed according to a first order reaction which goes to completion. The solution shows the effect which an impulse heating or cooling has on the vertical structure of the atmosphere. Thus the theory relates a non-periodic atmospheric heat release to a structure imposed on the vertical profile of the atmosphere. The temperature profiles computed from theory compare favorably with observations of Smith, et al. (1970) indicating that a means has been found to estimate the effects of such processes as the release of latent heat of condensation in the troposphere on the upper atmosphere.

THEORY

The atmosphere is assumed isothermal, inviscid, non-conducting, one-space-dimensional, and initially quiescent. At an initial time an energy releasing process commences, and drives the subsequent wave motion. The fraction of reactant X in the atmosphere is assumed to be small. The system of governing equations is then expanded in terms of the small parameter X, and in integral solution asymtotic small X is obtained.

The reaction equation is of the form:

$$\frac{d\,\alpha}{d\,t} = k_F \, \rho \, (1 - \alpha)$$

where the fraction reacted, α, goes from zero to unity, ρ is mean atmospheric density, and k_F is a rate constant which, to zeroth order, is independent of temperature.

The linearized atmospheric equations are reduced to the following:

$$\frac{\partial^2}{\partial t^2} M[\theta] = e^{-z/2} f(\alpha)$$

where

$$\theta = e^{-z/2} T$$

and

$$M[\cdot] = \frac{\partial^2}{\partial t^2} - c^2 \frac{\partial^2}{\partial z^2} + \frac{c^2}{4}$$

where c is the speed of sound. The solution is of the form:

$$\theta(t, z) = \int_0^t W(t, z, \tau) \, d\tau$$

$$W(t, z, \tau) = \int_0^{tc-\tau c} \left[J_0\left(\frac{1}{2}\sqrt{(tc - \tau c)^2 - y^2}\right) \right] Q(\tau, z, y) \, dy$$

$$Q(\tau, z, y) = \frac{1}{2c^2} [\phi(\tau, z + y) + \phi(\tau, z - y)]$$

where ϕ is a non-periodic driving function. The above solution was integrated numerically for an intentionally large amount of condensation. It was assumed that 20% of the water vapor from air saturated at the 5 km level was condensed over an altitude range of approximately one half scale height. A reaction half time of 3 hours was used. The development of the temperature perturbation is shown in Figure 1.

Persistent features in the temperature structure of the mesosphere have been observed in many sets of serial soundings. For the purpose of this

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discussion, the pair of profiles shown in Figure 2, which were conducted 2 hours apart from Barrow, Alaska (71°N) on December 13, 1968, will be examined because they exhibit the slowly changing structure similar to that generated by the model. Note the similarities between the two profiles, and that certain features are displaced vertically downward with time. For example, the minimum temperature region denoted "a" appears at an altitude 2 km lower in the second profile than in the first. The abrupt change in the magnitude of the lapse rates at "b" occurred in both soundings and is displaced downward by about 1 km with time. The altitude of the stratopause, indicated at "c", has descended by approximately 6 km during the elapsed 2 hours between observations.

The apparent vertical movement of these features may be questioned since the grenade technique cannot resolve the vertical structure of the atmosphere to less than the vertical distance between two consecutive grenade explosions. Simulations have shown that the displacement of the feature at "a" could result from the differences in the layering from one experiment to the other; however the differences at "b" and "c" are probably real since they could not be reproduced by varying the layering but only by the temperature structure itself. The grenade technique is known to underestimate the magnitudes of relatively shallow (i.e., less than 3-4 km thick layers) temperature maxima and minima and, as already mentioned, it lacks the vertical resolution to accurately locate the altitude of such structure. It is quite accurate in describing the remainder of the profiles, however.

The gradual nature of the temperature changes indicates that a long time scale is involved, and the vertical size of the persisting features suggest that a

longer period mechanism is responsible. This does not imply that the usual gravity waves are not present, it merely proposes a special case as an explanation for the phenomena observed.

In order to extract the temperature changes from the persisting structure, the first profile was subtracted from the second in Figure 2, and smoothing applied in the form of a 10 km running mean to filter out the smaller scale variations. Figure 3 shows the smoothed temperature change as a function of altitude for the profiles given by Figure 2. The wave-like profile has a peak to peak amplitude of approximately 15° and a vertical wavelength approaching 40 km (roughly 5-6 scale heights). This result resembles the structure generated by the model which is shown in Figure 1, where the complete vertical wavelength extends from the surface to about 7 scale heights. Although the model overestimates the amplitude of the temperature change by a considerable margin, this is undoubtedly due to the unrealistically high percentage (20) of water vapor which is condensed in the reaction layer in the model, and the effects of comparing a one dimensional model with the real atmosphere. It should be noted that since the model predicts the survival of the temperature structure generated by the release of latent heat of condensation for periods of up to a day, the structure thus generated can be transported horizontally by the prevailing drift and need not have originated in the troposphere immediately below the observations.

Thus the theory for a mechanism which might explain some of the variability in the temperature (and density) structure of the mesosphere in terms of

tropospheric events has been developed and compared with observational data. In general character, the model and an observed case appear to compare favorably. The design of a suitable experiment to establish the existence of this mechanism with greater certainty than is possible with available data remains to be accomplished.

REFERENCES

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Smith, W. S., Theon, J. S., Casey, J. F., and Horvath, J. J., 1970: "Temperature, pressure density, and wind measurements in the stratosphere and mesosphere, 1968" NASA Technical Report TR R-340.
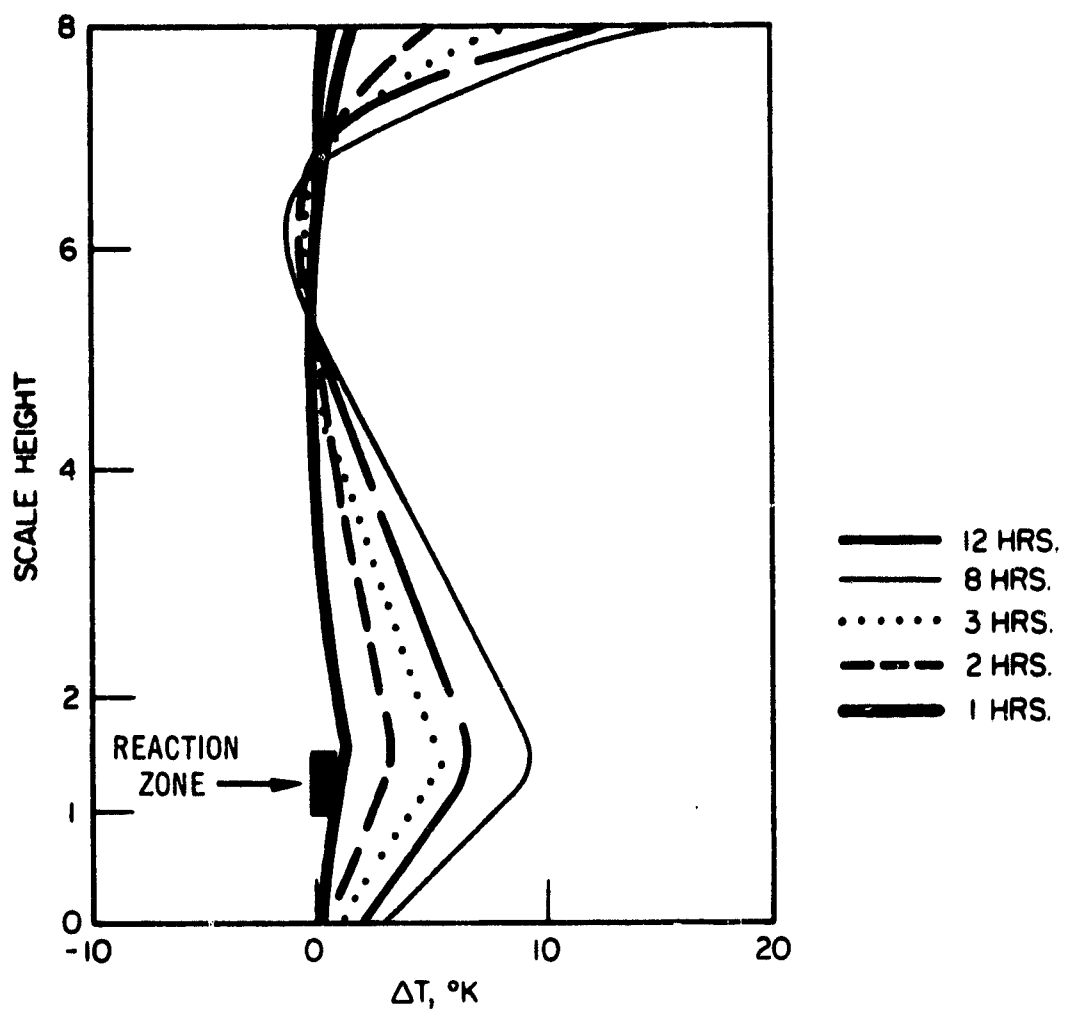
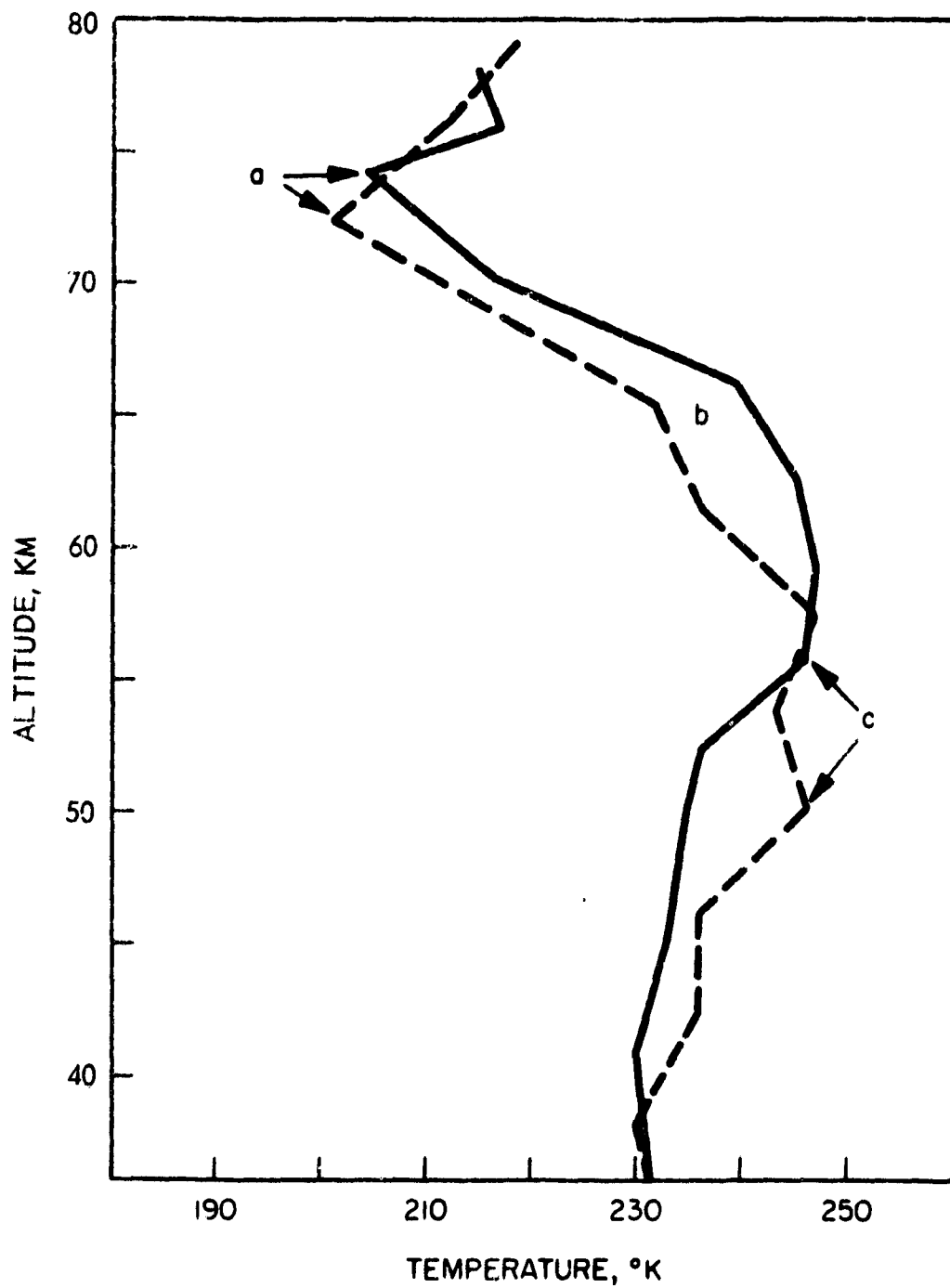Figure 1. Temperature changes generated by latent heat release in the troposphere in the model.

Figure 2. Temperature profiles over Barrow, Alaska (71°N) on 13 December 1968. The solid curve represents the 0459 GMT observation and the broken curve the 0659 GMT observation.
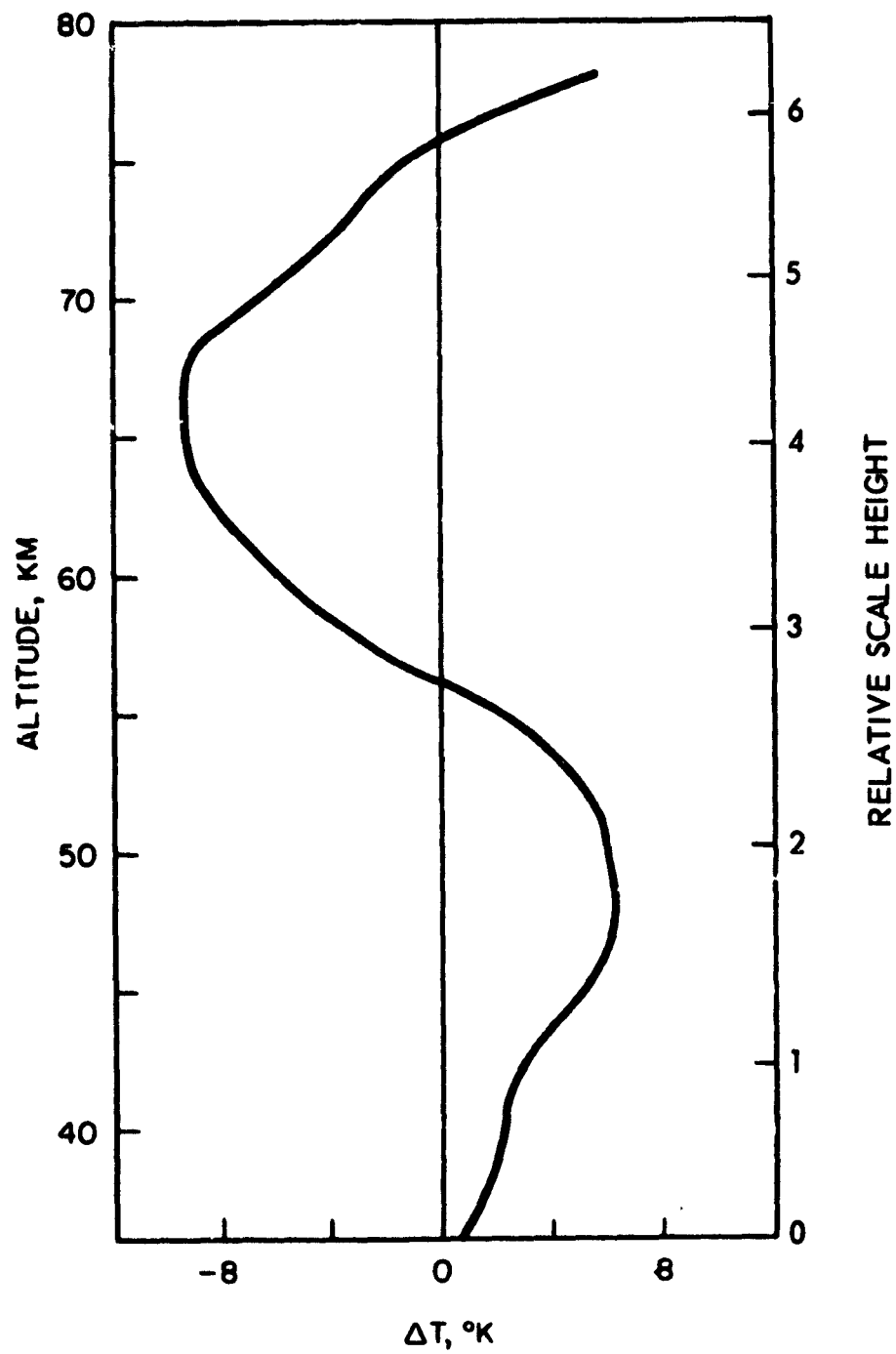
Figure 3. The smoothed temperature change which occurred during the interval between the soundings given in Figure 2 as a function of altitude.